Investigating Implicit Gender Bias and Embodiment of White Males in Virtual Reality with Full Body Visuomotor Synchrony

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ABSTRACT

Previous research has shown that when White people embody a black avatar in virtual reality (VR) with full body visuomotor synchrony, this can reduce their implicit racial bias. In this paper, we put men in female and male avatars in VR with full visuomotor synchrony using wearable trackers and investigated implicit gender bias and embodiment. We found that participants embodied in female avatars displayed significantly higher levels of implicit gender bias than those embodied in male avatars. The implicit gender bias actually increased after exposure to female embodiment in contrast to male embodiment. Results also showed that participants felt embodied in their avatars regardless of gender matching, demonstrating that wearable trackers can be used for a realistic sense of avatar embodiment in VR. We discuss the future implications of these findings for both VR scenarios and embodiment technologies.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *Interaction techniques*;

KEYWORDS

Virtual Reality (VR), Embodied Avatars, Implict Gender Bias, Implicit Association Test (IAT)

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CHI 2019, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5970-2/19/05…$15.00
https://doi.org/10.1145/3290605.3300787

ACM Reference Format:
Sarah Lopez, Yi Yang, Kevin Beltran, Soo Jung Kim, Jennifer Cruz Hernandez, Chelsy Simran, Bingkun Yang, Beste F Yuksel. 2019. Investigating Implicit Gender Bias and Embodiment of White Males in Virtual Reality with Full Body Visuomotor Synchrony . In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4–9, 2019, Glasgow, Scotland UK*. ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3290605.3300787

1 INTRODUCTION

In this paper, we investigate the effects of embodiment and implicit gender bias on White males using full body visuomotor synchrony in immersive virtual reality (IVR). The importance of investigating gender in a first-person perspective in IVR has been stressed by [22], especially as IVR has been shown to be powerful in inducing body transfer illusion [40]. Males can identify with being a female child with only tracking of the head and haptic touch [40]. Male participants accept having female hands in virtual reality (VR) with tracked hands [37].

An individual's virtual self-representation can affect their behavior [45] and cognition [22, 31]. Research has shown that when White people embody a black virtual avatar using full body visuomotor synchrony, their implicit racial bias can be reduced [30], even over sustained periods of time [7]. Similarly, people embodied as elderly people [46], a cow [2], and even a degrading coral reef [2] have shown a change in attitude towards their subject of embodiment.

However, there is also evidence to suggest that VR embodiment can also create stereotype activation: the automatic activation of concepts and stereotypes in the presence of relevant stereotyped features such as gender or race [10]. For example, Groom et al. [19] found an increase in implicit racial bias in White participants who were embodied in black virtual avatars. It is generally thought that there are two reasons for this discrepancy in findings [7, 30]: 1) the VR scenario in [19] was a job interview which is a situation where implicit racial bias typically occurs, and 2) participants did not employ full body visuomotor synchrony, that is, full body tracking between the virtual body and physical body.

As a result, in this paper, we present the same neutral or 'benign' VR scenario as [7] by having participants carry out Tai Chi, especially as this is a convenient way to have participants move their bodies without breaking expensive hardware and crashing into walls. Secondly, it is critical that we have highly precise tracking of the body movements to create a realistic sense of embodiment in the virtual avatar. In this paper, we use the HTC Vive wearable trackers on 9 locations of the body to achieve this (rather than a motion capture suit as used in [7, 30]). This allows us to run the study on participants with different heights and breadths as well as to make a technical contribution of full body visuomotor synchrony with wearable trackers only. Thus, the contributions of this paper are:

(1) Build, develop, and assess full body visuomotor synchrony using HTC Vive trackers as a means of of embodiment in a virtual avatar.
(2) Demonstrate the effects on implicit gender bias of embodying White males in male and female avatars with full body visuomotor synchrony in IVR.
(3) Discuss the implications of the findings and make recommendations for virtual reality scenarios in terms of implicit gender bias and embodiment techniques.

2 RELATED WORK

Effects of Gender Self-Representation in VR

The act of an individual conforming to their digital or virtual self-representation, independently of how others perceive them, has been coined the Proteus Effect [45]. For example, participants embodied in more attractive or taller avatars interacted in closer proximity and acted more confidently, respectively [45]. Pena et al. [31] investigated the cognitive effects of the Proteus Effect and found participants with avatars in black uniforms or Klu Klux Klan uniforms developed more aggressive game playing, wrote about more aggressive themes, and had lower levels of affiliation [31].

Yee et al. [47] examined behavioral data from the online game *World of Warcraft* (WoW) and found that male avatar players were more likely to engage in killing while female avatar players were more likely to engage in healing activities. However, these gender stereotypes were socially constructed, as there was no significant difference in terms of players' *real* gender. Lee et al. [22] investigated whether avatar-based virtual gender representations influence cognitive performance associated with gender-related stereotypes, specifically, quantitative abilities. Participants of both genders represented by third-person perspective male avatars, when competing against female avatars, demonstrated a significant increase on a mental arithmetic task.

Aitamurto et al. [3] investigated gender inequality attitude using the film *Uturn* by NativeVR with a head-mounted display. The storyline has a lead female engineer whose work goes unrecognized by a male CTO. Participants who chose the female character's perspective showed greater responsibility for resolving gender inequality, with the opposite effect on those who chose the male character. Due to the choice participants had of whether to take the male or female's character, reinforcement of preexisting stereotypes could have occurred [3]. Muller et al. [24] designed a dispositional empathy game in VR using gender stereotypes (no tracking). Players inhabited both male and female characters in situations of sexism. There was some increase in dispositional empathy and willingness to act against sexism [24].

Full Body Visuomotor Synchrony in VR

Several full-body tracking systems exist, including magnetic systems, camera-based systems, Microsoft Kinect systems, motion capture suits, and several combinations of these systems. The Microsoft Kinect is a depth sensor that has previously been used to achieve embodiment in virtual reality [42]. The advantages to this system are that the user does not need to wear any additional sensors or suits, and it is relatively inexpensive. Two crucial disadvantages to the Kinect are the relatively high latency of tracking movement, and the relatively high inaccuracy when compared to other systems [4, 26, 42]. Several studies have used the Kinect system to capture full body avatars of users [23, 38, 43], as well as using the Kinect to track user movement within virtual reality [9, 29]. The Kinect system can achieve full body tracking of users within virtual reality [4, 33] demonstrating competitiveness with more expensive marker-based systems which utilize motion capture suits [11].

Motion capture suits and other marker-based systems use several markers placed on the user's clothing or on a tight form-fitting suit which the user wears. Several studies have successfully demonstrated achieving the body ownership illusion between the user and their virtual body using motion capture suits to track the body, and an HMD to track the head such as[6, 8, 20, 21] . Motion capture suits have been used to demonstrate that having a fully tracked body increases a user's sense of embodiment [41]. Disadvantages to marker-based systems include the requirement of the user to wear several markers or a special kind of suit. Such suits present limitations for experimenting on users with different body-types, for example, only female participants were used in [7, 30] as the motion capture suits were too small for most male participants. Motion capture solutions are usually far more expensive, more time consuming to use, and require a controlled lighting environment to work well [42].

A less intrusive solution to full body tracking than motion capture suits is the use of wearable sensors or trackers. Wearable inertial measurement units (IMUs) have been used in conjunction with other systems to achieve full body tracking, e.g., [4, 32]. Ahn et al. [2] used a undisclosed number of wearable LED markers to have participants embody a cow. From Figure 1 in [2], it appears as though the trackers are worn only on the wrists of participants. Schwind et al. [37] used an Oculus Rift headset and the Leap Motion hand tracking system to demonstrate how gender effects the perception of avatar hands in virtual reality. The Leap Motion system only provides hand tracking. While these examples were sufficient for the scenarios described, the embodiment of a human performing the complexity of Tai Chi movements requires a greater number of trackers and high precision levels. Wearable HTC Vive Trackers demonstrate high accuracy and low latency [26]. The Vive tracking system uses two diametrically opposed infrared laser emitting stations and wearable trackers with photodiodes that detect when they are hit by the lasers [26, 27].

Stereotype Activation and Perspective-Taking

When examining related work on implicit biases and VR, it is helpful to contextualize and categorize them in terms of stereotype activation and perspective-taking. Stereotype activation is when features such as gender and race activate stereotypes about that group [10]. Perspective-taking is the idea that imagining oneself as a member of an out-group can reduce stereotypes about that out-group [12], thereby causing a reduction in bias [14]. VR allows for the experience of viewing onself embodied as a different person in a more visceral manner than simply imagining oneself as that person [19]. We categorize VR studies that have full or partial tracking of the participant's physical body in terms of stereotype activation and perspective-taking.

Groom et al. [19] observed racial stereotype activation with first person perspective taking in VR (head-tracking only). They found greater implicit racial bias using the Harvard Implicit Associated Test (IAT) and greater explicit racial bias in White participants who were embodied in black virtual avatars than those embodied in white virtual avatars. In [19] they state that their findings do not support perspective-taking since their study did not result in a reduction in bias. It is important to note that this study used the specific context of a job interview led by a White confederate which could have caused stereotype activation which overwhelmed any positive effects of perspective-taking. Banakou et al. [7] argue that this induced social setting of a job interview is negatively related to racial biases and race discrimination. In addition, while Groom et al.'s [19] participants were embodied in a virtual avatar, there was no full body visuomotor synchrony. [19] only used correlated head movements that lasted 60-75s for embodiment which could have significantly reduced the feeling of embodiment for participants.

On the other hand, some studies have used perspective-taking of an out-group member in VR using neutral scenarios, which have resulted in a reduction in bias. Peck et al. [30] and Banakou et al. [7] found a reduction in implicit racial bias when putting White female participants in female dark-skinned virtual avatars compared to embodying them in light-skinned virtual avatars. There was a significant reduction in ΔIAT (ΔIAT = *post experiment IAT - pre experiment IAT*) [30], even over sustained periods of time [7]. Participants in both studies had full body visuomotor synchrony by wearing a motion capture suit and had an embodiment phase to explore and move their virtual body. In [30], participants were approached by other virtual female avatars who were either light or dark-skinned. In [7], participants carried out Tai Chi by following the movements of a virtual Tai Chi teacher. The scenarios in both papers were carefully chosen as '*benign*' social settings [7] in order to avoid any negative stereotypes related to race and can be categorized as *neutral scenarios*.

There are also cases of reduction in bias or increase in empathy when the VR *scenario is negatively stereotyped* or charged rather than simply being neutral. In Ahn et al. [2], participants got down on their hands and knees, viewed themselves as a cow, and were poked by a confederate with a cattle prod/haptic stick as they were about to be loaded onto a truck. In another study, when embodied as a coral reef, participants felt the ground shake and were poked with a haptic stick as they saw themselves decaying. Participants experienced an increase in interconnectedness with nature by experiencing these negative effects with full embodiment compared to those who only watched a video [2]. Yee and Bailenson [46] had participants embody virtual avatars that were young and elderly (head-tracking only) and had them carry out tasks including carrying out a memory exercise to reinforce the fact that they were elderly and is negatively stereotyped with the elderly. They found that some measures showed a significant reduction in negative stereotyping of the elderly [46]. [2] and [46] used scenarios that were negatively stereotyped for perspective-taking and observed increased interconnectedness and reduced bias, respectively.

Following [19]'s direct comparison of stereotype activation and perspective-taking as two alternative hypotheses, we can categorize embodiment in VR studies into two main categories (Table 1): 1) increase in bias/stereotype activation such as [19] and, 2) reduction in bias/perspective-taking. The latter we can divide into two further subcategories: a) studies that create a neutral scenario [30, 6], and b) studies that create a non-neutral or negatively charged scenario [2,24] to reduce bias or increase empathy.

Category	Effect of Tracking in VR	Researches
1	Stereotype Activation	[19]
2a	Perspective-Taking - Neutral Scenario	[30] [7]
2b	Perspective-Taking - Negatively Stereotyped Scenario	[46] [2]

Table 1: Categorization of studies investigating bias or empathy using partial or full tracking in VR in terms of stereotype activation and perspective-taking.

Figure 1: Left: Participant wearing all nine HTC Vive trackers and headset (highlighted by red cirles). Right: HTC Vive trackers, headset, and accompanying devices.

3 VR SYSTEM: FULL BODY VISUOMOTOR SYNCHRONY AND AVATAR TRACKING

To present the technical system, we first provide some context: the participant will be embodied in either a male or female avatar. After a period of adjustment and practice moving their virtual body, they follow the movements of a virtual Tai Chi teacher for 8 minutes, similar to [7]'s methodology. This section describes the system that we created for full body visuomotor synchrony in VR and avatar creation and tracking using wearable trackers.

Equipment and Physical Environment

We used Unity (version 5.6.1f1 personal), SteamVR (version 1533664367), HTC Vive VR equipment, and a PC (Windows 10 Pro 64-bit 10.0 build 17134 with an Intel(R) Core(TM) i7-6700 CPU @ 3.40GHz 8 CPUs with 64GB of memory. We used an NVIDIA GeForce GTX 1050 Ti graphics card with 4GB display memory). The tracking area in the physical room was 260cm × 210cm × 230cm (height), which is contained by two HTC Vive base stations. At the center of the tracking area, a blue cross indicates the participant's location during the study. Participants wore an HTC Vive Headset which employs two 1080 × 1200 pixel displays with an overall 2160 × 1200 resolution, and a 110 degree field of view (FOV) at 90 Hz. [27] In addition, participants also strapped 9 Vive trackers on their hands, elbows, knees, feet and back to track their body movement (Figure 1).

Figure 2: Male and female avatars used for embodiment.

Tracking

The HTC Vive tracking system provides high accuracy, low jitter (< .02 cm), low system latency (22 ms), and tracking of objects in 6 degrees of freedom[27]. The tracking system uses two infrared laser emitting units (base stations) to track wearable trackers. These trackers are covered in photodiodes which register when they have been hit by a laser from the base stations [27]. The trackers then communicate with the PC via USB wireless dongles and the SteamVR software. Each base station was mounted on a tripod 2.3 m high and placed in two opposing diagonal corners of the room. The SteamVR play area is a rectangle slightly smaller than the dimensions of the physical lab room. Each tracker is strapped to the users body and limbs, and is then assigned to its corresponding avatar model bone in Unity. This is accomplished using the FinalIK script, VRIK [34].

FinalIK is a Inverse Kinematics solution in game development. In VR, the avatar's body is an articulated body which is similar to a tree of linked chain. A forward kinematics algorithm can take the avatar pose as input and calculate the end effector position and rotation. However, in our system, participants only attached trackers onto some, not all, body parts which does not provide enough information at run time. We therefore used an inverse kinematics algorithm to generate the avatar's pose to reach head, hands and feet position and rotation tracked by the Vive trackers in real-time.

Due to discrepancies between the participants' physical bodies and the virtual avatar bodies, slight adjustments to the virtual model must be made within Unity. The model GameObjects are then made to match the tracker positions relative to the body, with the in-game model GameObjects. Adjustments usually include altering the model's scale to match the height of the participant, moving the bend goals for the knees and elbows to make sure that the model's knees bend in the same direction as the participant's, and rotating the feet and hands. FinalIK Twist Relaxer scripts are then added to each upper arm and forearm of the model, to prevent the model's mesh from distorting when the participants rotate their wrists.

Avatar Creation

We needed to create two types of avatars for this study: 1) A male and female avatar for self-representation and embodiment, and 2) A virtual Tai Chi teacher to lead the participant through Tai Chi movements. We discuss the creation, tracking, and preliminary studies on the avatars.

Avatars for Self-Representation and Embodiment. The male and female avatars that were used for first person perspective taking for self-embodiment were created using Adobe Fuse CC (Figure 2). We chose stock faces and body types provided in Adobe Fuse CC of White men and women. From the clothing and accessory options, we selected items that were associated with physical activities such as t-shirts and sneakers. Once the outward appearances were complete, each avatar was then exported to Mixamo[1]. In Mixamo, the avatars were rigged using the auto-rig feature. Once rigged, the avatars were downloaded from Mixamo in Unity FBX format, and then imported into a scene in Unity to be used for a pilot study. These avatars were tracked using the technique described in the subsection above.

We ran a preliminary study on four male participants to ensure that they felt embodied in both the male and female avatars with the wearable trackers. We also asked participants if they felt physically attracted to the avatars. It was important that there were neutral levels of physical attraction to the virtual avatars in order to avoid objectification which could lead to a decreased sense of embodiment. Participants rated their answers to the questions with a Likert scale of 1 (Strongly Disagree) to 5 (Strongly Agree). Results showed that participants felt embodied in both male and female virtual avatars, and that they did not feel physical attraction towards them.

Tai Chi Teacher Creation and Tracking. The Tai Chi teacher was created using Blender[2], an open source 3D modeling software program. The model appearance was designed to be as gender neutral as possible due to possible confounding factors if the teacher were either male or female. For example, in [7] when testing race, they originally made the Tai Chi teacher Asian, and later changed this to Caucasian due to confounding factors. The Tai Chi teacher model's dimensions and features were taken from a mannequin and altered. After importing two 2D sketches into Blender, the model was created based on those two sketches. While humanoid in appearance, the aesthetic details of the model were kept to a minimum with the model lacking fingers, toes, skin, hair, facial features, clothes, and any other features which may be associated with gender. The base color of the model is a shade of orange, distinctly inhuman, while also avoiding being a color commonly associated with a gender. To avoid characteristics of the hips from being attributed to a gender, the model's hips have a slight spherical shape and are the same width as the shoulders. Previous iterations had slightly more box-shaped hips, which gave a slightly masculine appearance. Other earlier iterations were pelvis-shaped and wider, which at times gave the model a more feminine appearance. The shoulders were also narrowed and rounded, to avoid a more masculine appearance. The in-game model height appears to be about 5 feet 8 inches. The model is perfectly symmetric.

After creating the model in Blender, it was exported as an FBX file, and uploaded to Mixamo, a 3D character animation website, where it was manually rigged and exported as a Unity FBX file. The model was rigged using symmetry, and has a Skeleton LOD set to Standard Skeleton. Mixamo then creates bones based on humanoid anatomy, and each of these bones are represented in Unity by a corresponding Game Object. The model was then imported to Unity as a humanoid model (Figures 4 and 3). The model was tracked using FinalIK + VRIK in combination with nine HTC Vive trackers and the HTC Vive head mounted display, and the Tai Chi movements were recorded using a unity recorder asset. Each move was recorded separately, with 1-2 second pause in between each move. The move set loops twice, allowing for participants to take a break in between the sets. The Tai Chi movements were chosen for ease of learning, low difficulty, and avoiding overly strenuous physical exertion.

The Tai Chi teacher animation which was used in the experiment was created by motion capture based on our full body visuomotor synchrony system and Unity runtime animation recorder plugin. [25] In the recording, a human performed Tai Chi in the physical world which was recorded in Unity including the transform information of the game object under Tai Chi teacher avatar's hierarchy for each time frame. Finally, the transform information was used to generate Tai Chi animation based on their time frame.

A preliminary study was conducted on the appearance of the teacher to ensure gender neutrality. Eleven male participants were asked to watch a video of the model doing Tai Chi, followed by the question "This avatar appears gender neutral" on a Likert Scale of 1 (Strongly Disagree) to 5 (Strongly Agree). Ten out of the 11 participants agreed or strongly agreed that the model was gender neutral.

Adjustments

Participants wore trackers on their feet, legs, arms, hands, and lower back and the HTC Vive headset. Participants had

[1]www.mixamo.com
[2]www.blender.org

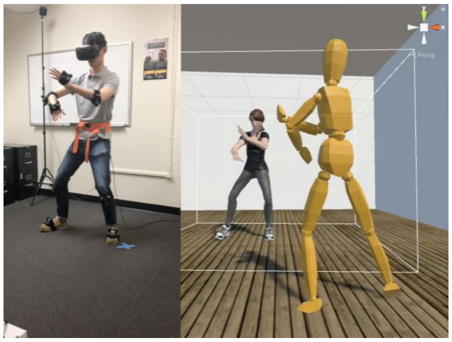

Figure 3: VR and avatar setup: Participant's physical body (left) and tracked virtual body in female avatar (right). Participant follows movements of the virtual Tai Chi Teacher.

their eyes closed while adjustments were being made to make the embodiment more realistic. During this time, we adjusted the virtual body so that it more closely fit the participant's real body. This included adjusting the virtual avatar's height or rotating a virtual body part to best match the participant's real body. Once all adjustments had been made, participants were asked to open their eyes and were then introduced to the virtual world and their virtual bodies.

4 METHODOLOGY

Experimental Design

Twenty-four White, male participants, aged 18 to 64 (mean age of 29.8, SD of 12.63) took part in a between-subject design. The participants were a mix of students and staff at a West Coast university and members of the general public and were compensated $25 for the completion of two studies. The participants were embodied in either a male virtual avatar or a female virtual avatar. All participants completed two studies. During the first study, the participants carried out an Implicit Association Test (IAT) in virtual reality (pre-IAT). After a period of two to seven days, participants returned for the second study to carry out the main experiment with full body-tracking with a virtual avatar (their first encounter) followed directly by the postIAT. Participants put on the HTC Vive head-tracker and nine HTC Vive trackers on their body (feet, knees, elbows, the back, and on dorsal-side of the hands) with Velcro straps. An adjustable belt was used to put the tracker on the back. Once the participant was in the virtual room, adjustments were made to the virtual avatar to tailor the avatar's body specifically to each participant such as proportionality of the limbs and adjusting for height to convey an accurate feeling of embodiment. Participants were instructed to move their physical body through a series of instructions for 5 minutes, look at their reflection in the virtual mirrors and look down at their body (Figure 4) to get acquainted with their VR bodies. The participants were instructed to follow the movements of the virtual Tai Chi teacher for 8 minutes. This is very similar to [7]'s methodology and chosen activity. Tai Chi is a good way to get participants to move in VR in order to get the feeling of embodiment and motor control without causing damage to the participants and equipment (as they cannot see the physical world). Once the Tai Chi session was completed, participants performed the second IAT (postIAT). [30] and [7] administered tehir postIATs in VR. In this work, both IAT tests were conducted in VR to keep consistency between the pre and postIATs. This pretest-posttest design was the same as [7, 30]. The mean number of days between pre and postIAT for both conditions was 3.17 days (SD 1.03 for female avatar condition, SD 1.75 for male avatar condition). Participants were then given a post-experiment questionnaire (Table 2) and asked the following interview questions: 1) *What did you think of the experience?* 2) *Was there anything that made you feel embodied or disembodied in the virtual avatar?* and 3) *Do you have any other comments?*

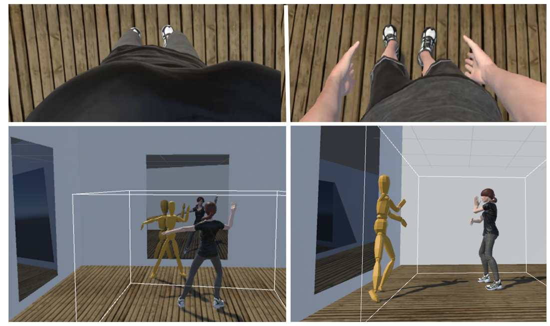

Figure 4: Top: Participant's point of view when looking down at virtual body in female (left) and male (right) avatar. Bottom: VR setting with virtual mirrors to the front and left of participant. Participant is following movements of virtual Tai Chi teacher.

IAT

The IAT is a test to detect the strength of a person's automatic association between mental representations of objects. It was introduced by [16] and has since been developed [18] and used in psychological sciences ([5] has a good review). The Gender-Career IAT[3] requires that participants quickly categorize words into pairings of Female-Career and Male-Family, and Female-Family and Male-Career. Words to be cateogorized include *Male* words such as 'Ben' and 'Paul', *Female* words such as 'Rebecca' and 'Michelle', *Career* words such as 'Career' and 'Corporation', and *Family* words such as 'Wedding' and 'Marriage'. The final IAT score is calculated by the improved algorithm based on participant's latency

[3]implicit.harvard.edu/implicit/user/agg/blindspot/indexgc.htm

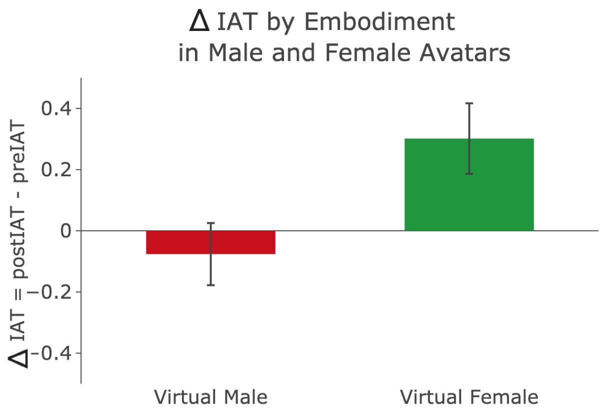

Figure 5: Bar chart (means and standard errors) of ΔIAT by embodiment (male or female). For those embodied in a male avatar (red) the mean ± SE is -0.08 ± 0.010 and for those embodied in a female avatar (green) 0.30 ± 0.115.

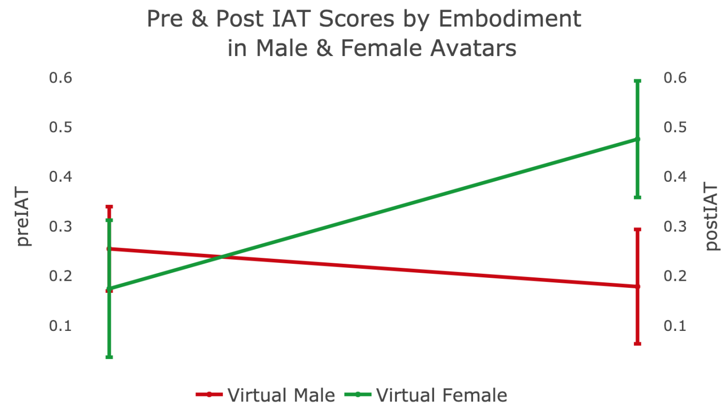

Figure 6: For male-embodying participants (red), preIAT mean ± SE is 0.255 ± 0.085 and postIAT mean ± SE is 0.179 ± 0.115. For female-embodying participants (green), preIAT mean ± SE is 0.174 ± 0.138 and postIAT mean ± SE is 0.476 ± 0.117.

and accuracy, described in [18]. A higher positive IAT score interprets as higher implicit gender bias to group the female gender with family-orientated words and the male gender with career-orientated words. The ordering of the pairings can affect IAT results, therefore we counterbalanced the order of combined blocks as recommended by [18, 28] and carried out by [7].

Virtual Setting

The virtual setting consisted of a 5.67 m by 5.82 m room with a large virtual mirror placed at the front of the room and a mirror on the left wall (Figure 4). The room was designed to look like a Tai Chi studio with wooden floors and blank walls. The participant stood 1.94 m in front of the virtual mirror facing the front. A virtual Tai Chi teacher stood 0.53 m in front of the avatar facing them (Figures 3 and 4).

5 RESULTS

IAT Data

We evaluated and computed ΔIAT by subtracting the postIAT score from the preIAT score, the same as [7, 30]. We carried out Shapiro Wilk tests that verified that the data was parametric ($W = 0.97104, p = 0.6927$). Results showed that there was a significant difference in the mean ΔIAT for those embodied in a female virtual avatar (μ = 0.301, σ = 0.399) and for those embodied in a male avatar (μ = -0.076, σ = 0.352) ($t(22) = -2.46, p = 0.02; d = 1.00$). The means and standard errors are shown in Figure 5. Results also showed that female-embodying participants actually had overall mean increases in postIAT scores while male-embodying participants had a decrease in postIAT scores. For male-embodying participants, preIAT mean ± SE is 0.255 ± 0.085 (n=12) and postIAT mean ± SE is 0.179 ± 0.115 (n=12). For female-embodying participants, preIAT mean ± SE is 0.174 ± 0.138 and postIAT mean ± SE is 0.476 ± 0.117. The means and standard errors are shown in Figure 6. Results of the Spearman correlation indicated that there was no association between attraction to the avatar and ΔIAT for those who were embodied in a female virtual avatar ($r_s(10) = -0.049, p = 0.880$) and a male virtual avatar ($r_s(10) = 0.025, p = 0.523$).

Questionnaire Data

Participants' subjective ratings showed that they felt a strong sense of embodiment. Figure 7 compares the ratings (from Table 2) of MyBody (Q1) compared to TwoBodies (Q2). Ratings of MyMovements (Q4) also showed that participants felt a strong sense of body ownership and motor control even if the avatar did not look like them (MyFeatures (Q5)). Figure 7 compares the ratings of MyMovements with MyFeatures. Results also showed that most participants were generally not physically attracted to the avatars (Figure 8).

Interview Data

Embodiment Using Visuomotor Synchrony. Many participants had positive feedback about the sense of embodiment in the system regardless of whether they were embodied in male or female avatars. Here are some example responses:

"I felt embodied just being able to see the arms and legs move, my head move around as the [avatar] was, and being able to raise my arms and see that reflected in the virtual reality world. It felt fairly natural. I didn't feel disembodied at all. It felt like I could be at ease there... I hadn't run across that feeling in virtual reality before where you are actually feeling as though you are present, because I've been in a virtual reality

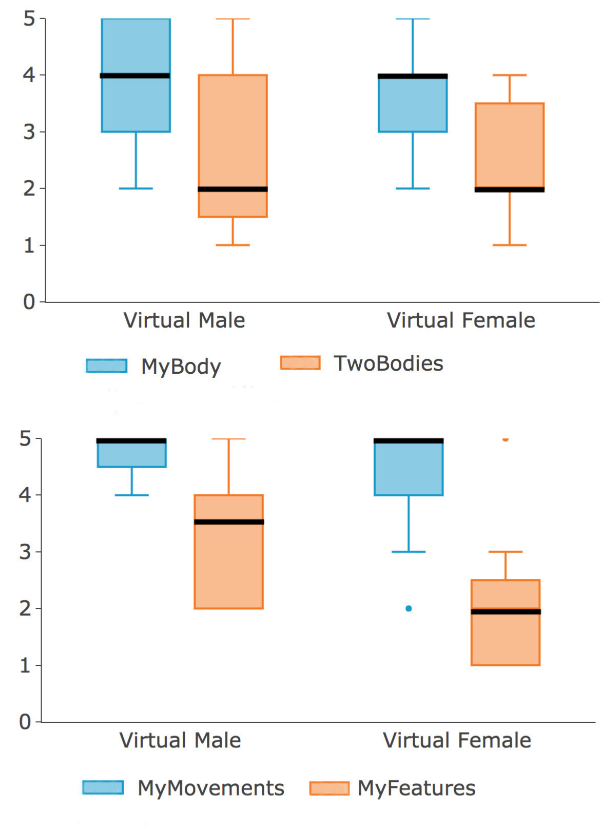

Figure 7: Box plot of body ownership questions for top: MyBody and TwoBodies and bottom: MyMovements and MyFeatures. The thick black horizontal lines are the medians, the boxes are the interquartile ranges, and the whiskers extend to ±1.5 x IQR, or the range. Individual points are outliers.

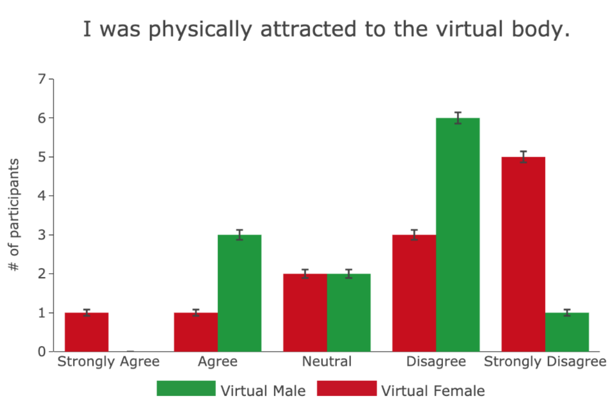

Figure 8: Bar graph of participants' subjective ratings on physical attraction of male and female virtual avatars

	Variable	Question
Q1	MyBody	I felt like the virtual body was my own.
Q2	TwoBodies	I felt as if I had two bodies.
Q3	Attraction	I was physically attracted to the virtual body.
Q4	MyMovements	I felt that the movements of the virtual body were caused by my own movements.
Q5	MyFeatures	I felt that my virtual body resembled my (real) body in terms of shape, skin tone, or visual features.

Table 2: Post-experiment questions rated on a Likert scale of 1 (Strongly Disagree) to 5 (Strongly Agree)

situation before and it felt unnatural... it ended up feeling fairly natural to be in there." - Subject 235 Female Avatar

"I was surprised at how reactive the virtual body was to my own movements. It was very accurate...when I put my hand up in front of my face then the virtual hand was in the exact same spot I would expect my real hand to be."- Subject 214 Male Avatar.

"It was doing what I was doing for sure. I mean for sure it was responsive. It wasn't delayed or lagged. [And] it was smooth. Definitely it did look like me with long hair and it was pretty funny."- Subject 213 Female Avatar.

Two of the participants expressed that they would have liked the fingers to be tracked, such as:

"It felt somewhat realistic movement wise, except for the fingers. If the fingers moved, I think it would've been even more compelling. ."- Subject 223 Male Avatar

Two of the participants felt there was some inaccuracy with their shoulders. For example, one said:

"...the avatar's movements were reflected of my own because of the trackers being able to move my hands, shift my weight and I see that reflected in the avatar..But I would say that I felt disembodied when I look to the left at the mirror and I saw that my shoulders, my avatar's shoulders were tilted way more than my own shoulder, so that was very disembodying experience." - Subject 209 Male Avatar

Tai Chi Teacher. When referring to the Tai Chi teacher, participants used terminology that denoted gender neutrality such as "*that Tai Chi bot*", "*virtual coach*", "*little like yellow teacher*", and "*the thing*". This suggests that the teacher was perceived to be gender neutral, or that a gender was not easily assigned to it by participants.

6 DISCUSSION

Full Body Visuomotor Synchrony Using Wearable Trackers

The questionnaire and interview data show that participants felt a strong sense of embodiment. Figure 7 shows that the levels of body ownership are similar in both conditions. More interestingly, it also shows that participants felt like the virtual body was their own, in contrast to having two bodies, in both conditions.

Figure 7 shows that even though participants embodied in female avatars did not feel that the avatar resembled them in appearance, they still felt strongly that the movements of the virtual avatar were caused by their own movements. This denotes a sense of embodiment and motor control even though the virtual avatar did not resemble their physical self, particularly in the female avatar condition.

These findings are backed up by the interview data which also suggests that most participants felt embodied in their virtual avatars. This is very promising for wearable trackers as a mode of full visuomotor synchrony as wearable trackers are cheaper and usable for different body heights and shapes. Two participants did comment that they would have liked the fingers to be tracked. This is now possible and would increase a sense of embodiment using wearable trackers. Subsequent to the completion of this work, a proposed standardized questionnaire for embodiment in VR was published [15]. The questions asked in our paper were taken from previous studies on embodiment in VR such as [7, 30] and includes several of the questions in [15].

Implicit Gender Bias

Results showed that participants embodied in female avatars had significantly higher implicit gender bias than those embodied in male avatars (ΔIAT) (Figure 5) and that participants embodied in female avatars actually had a mean increase in postIAT scores compared to a decrease in those embodied in male avatars (Figure 6). As prior experience to the IAT has been shown to *reduce* subsequent IAT scores [17, 18], this makes the increase in postIAT scores for participants embodied in female avatars even more pertinent.

We had expected, or at least hoped, that implicit gender bias would be lower in participants that were embodied in female avatars, similar to [30] and [7]'s findings with a reduction in implicit racial bias in their investigations with race and VR. However, our findings were similar to [19]'s whose participants had an increase in implicit racial bias. It is now thought that [19]'s findings are due to the lack of full embodiment in the virtual avatars and the VR scenario, a job interview, which was a situation that can induce racial stereotype activation. Unlike [19], our participants were fully embodied in their avatars, and as shown by the questionnaire and interview data, participants did feel a strong sense of embodiment. We also know that the participants did not feel physically attracted to the female avatar as shown by Figure 8. Furthermore, results of the Spearman rank correlation indicated that there was no association between participants' attraction to the avatars and their ΔIAT score for those who were embodied in a female virtual avatar ($r_s(10) = -0.049, p = 0.880$) and male virtual avatar ($r_s(10) = 0.025, p < 0.523$). This suggests that the findings are not caused by objectification of the avatars due to physical attraction.

We discuss two possible explanations for the findings of increased implicit gender bias: 1) Frustrations in the learning process attributed to the most salient factor (gender) and 2) Stereotype activation due to a negatively stereotyped activity (sport) in the VR scenario.

The first possible explanation is based on Silverman et al. [39]'s findings that when one becomes someone else, and gets frustrated quickly by the new identity without learning coping skills, that the attributions to the new identity are negative. In [39], brief simulations of disability, such as blindfolding able-bodied people to simulate blindness, reduced participants' judgement of disabled peoples' capabilities. This was likely caused by the experiences highlighting *becoming* disabled, rather than the competencies and adaptations of *being* disabled [39]. Similarly, it is possible that participants found carrying out the Tai Chi task frustrating as they were *learning* Tai Chi rather than simply carrying out Tai Chi. In the swapped gender condition, participants may have attributed this frustration to the most salient factor, which was being female. Participant frustration was not measured, however 3 participants voluntarily made comments about the Tai Chi VR scenario as a *'learning experience'* or being *'really hard'* during the post-experiment interview.

The second explanation is that the VR scenario of Tai Chi likely triggered stereotype activation due to the fact that it is a sport/athletic activity and sports are generally negatively stereotyped for females, e.g., [1, 13, 35, 44], similar to how a job interview is negatively stereotyped for people of color in [19]. Participants embodied in a female avatar in this scenario may have experienced stereotype activation, evoking associations of gender stereotypes. As the postIAT was taken immediately afterwards, participants could have carried the stereotype associations with them, thus resulting in scores reflecting an increase in implicit gender bias. Thus, while the Tai Chi scenario may have been a 'benign' scenario for racial neutrality in [7], it was most likely not a gender neutral scenario.

If this explanation is true, what then could serve as a gender neutral scenario in VR to examine the effects on implicit gender bias? Sociologists specializing in gender, argue that there is no such thing as a gender neutral activity [44]. It is argued that a gender binary exists as an ideology that is widely adopted by society and has led to people wearing metaphorical gender binary glasses, that separate everything into masculine and feminine categories. While different people might have different strength prescriptions for these metaphorical lenses, everyone sees the world with some permutation of gender rules [44]. Gender rules are instructions for how to appear and behave as a man or a woman and apply to every area of our lives, from how we decorate our homes, to what careers and hobbies we pursue, to whom we should socialize with and how [44].

It may not be possible, due to gender bias and gender rules, to find a gender neutral activity in VR, as [7] put it, 'benign' enough to avoid implicit stereotypes and stereotype activation (category 2a in Table 1). Therefore, it is perhaps better to look at scenarios created by researches such as [2, 3, 24, 46] where the participant is subject to some kind of negative experience due to their avatar's gender or species with the intention of increasing empathy towards their situation or highlighting discrimination in order to reduce biases (category 2b in Table 1). In a similar vein, when it comes to trying to decrease implicit gender bias, we recommend VR scenarios which are purposefully designed to increase empathy and/or highlight prejudice as opposed to trying to be 'neutral', due to the difficulty of gender neutrality presented by the gender binary and gender rules [44]. VR settings where participants are subjected to stereotyped gender biases such as being ignored in a meeting at work or being catcalled on the street could be explored. Such scenarios would need full body visuomotor synchrony to convey a strong sense of embodiment. If we find that such scenarios can reduce implicit gender bias, even perhaps over sustained periods of time as with racial biases [7], this can seriously affect the way we build fully-embodied VR programs for gaming, education, human resources training, and much more.

IAT Validity

In this paper, we used the improved IAT algorithm by [18] over the conventional algorithm by [16] (the algorithms are presented and compared in Table 4 in [18]). The new algorithm affords reduced sensitivity to prior IAT experience particularly for pretest-posttest designs [18]. However, prior experience effect is not completely eliminated by the new algorithm and the order of administration should be counterbalanced, as carried out in this paper.

Prior experience with the IAT has been associated with a reduction in subsequent IAT scores for those who reported one or more prior uses [17, 18]. The fact that participants embodied in female avatars actually *increased* their mean postIAT scores in contrast to those embodied in male avatars (Figure 6) demonstrates the strength of the findings.

7 FUTURE WORK

Our findings raise several questions for future work. Firstly, a third condition where participants are embodied in a gender neutral avatar could act as another control, however, this is not easy task to do with a full-body humanoid as it relies heavily on subjective perceptions of gender neutrality with a wide range of possible individual differences. Secondly, a fourth condition where the participant is not fully embodied would be worth investigating to further explore the relationship between embodiment and effects on bias.

We only tested White males in this study therefore it is important to note that both other races and females need to be tested as well. Measuring the frustration levels of participants if they are learning a new task is an important variable to consider in future work as well. It is also worth investigating visuotactile synchrony on the effects of embodiment in conjunction with visuomotor synchrony in this context. Several studies found a strong sense of ownership using visuotactile synchrony in conjunction with first person perspective taking in VR such as [6, 8]. Lastly, it would be interesting to investigate potential differences in the movement tracking data across conditions.

8 CONCLUSION

Our findings show that there was a significantly higher level of implicit gender bias in participants embodied in female avatars compared to male avatars using full body visuomotor synchrony. Results also showed that implicit gender bias increased in postIAT scores in female-embodied participants in contrast to male-embodied participants. Questionnaire and interview data showed that participants felt strongly embodied in their virtual avatars. We suggest possible explanations for the findings, including the occurrence of stereotype activation due to a negatively stereotyped VR scenario. We recommend using VR scenarios that are purposefully designed to increase empathy and/or highlight prejudice as opposed to being 'neutral' when it comes to gender due to the gender binary and gender rules [44].

Finally, as the authors, it is important to openly acknowledge that we are not outside of sexism or implicit gender bias, regardless of gender. As stated by [36], by acknowledging our biases, we can start to identify problematic scenarios in technology and start to work towards solutions as human-computer interaction researchers.

ACKNOWLEDGMENTS

This work was funded by Craig Newmark Philanthropies, the Department of Computer Science, and the Faculty Development Fund from the University of San Francisco. We thank EJ Chung from the University of San Francisco and Donovon Ceaser from Cal State East Bay for insightful discussions.

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